Approaching the Problem of Regional Climate Simulation through a Global, Multi-Resolution Modeling Approach: Successes and Challenges

Todd Ringler

Theoretical Division
Los Alamos National Laboratory

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Los Alamos NATIONAL LABORATORY EST. 1943

Climate, Ocean and Sea-Ice Modeling Project
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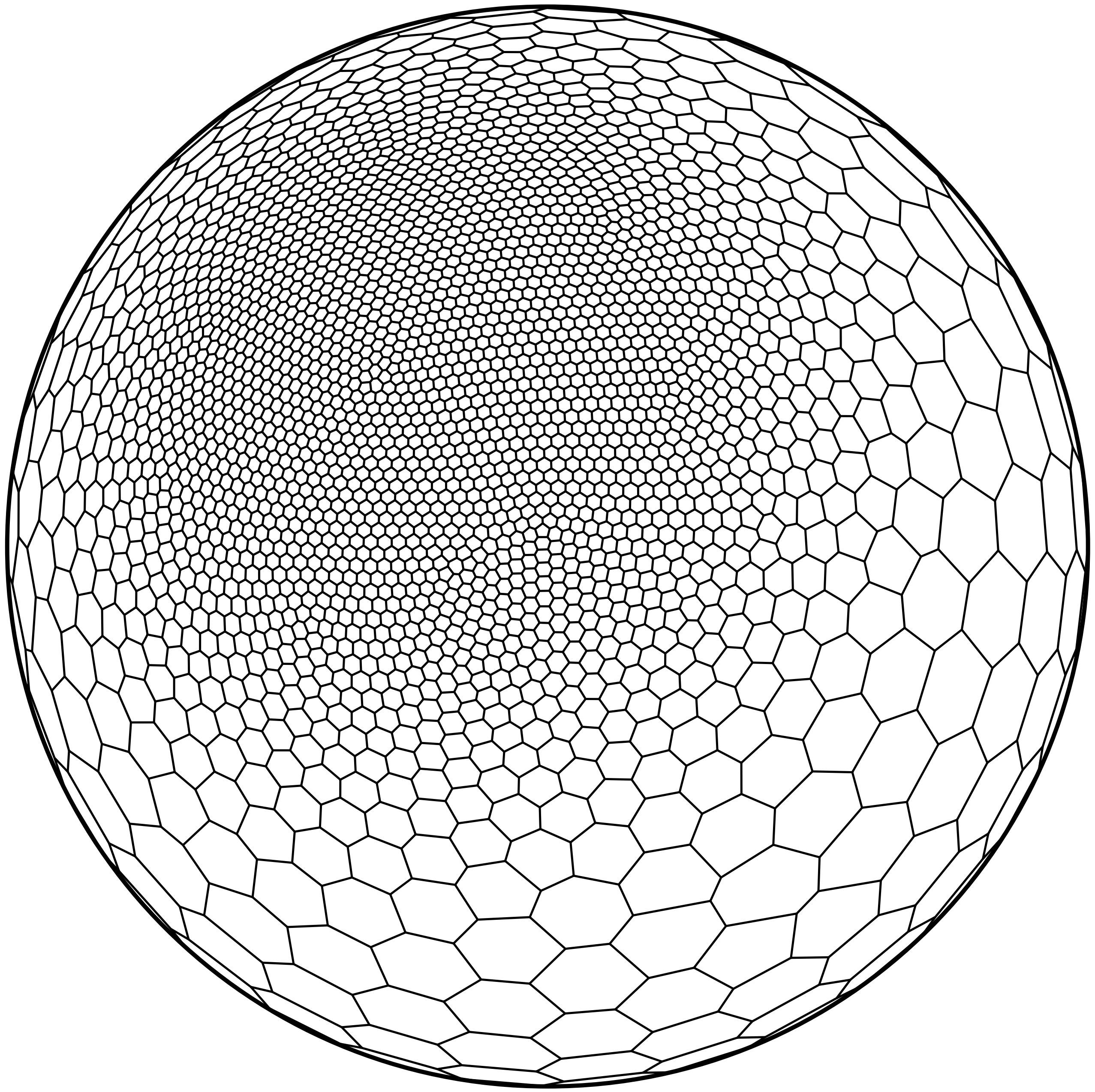
Florida State: Max Gunzburger

South Carolina: Lili Ju

Approach based on Smoothly-Varying, Conforming Meshes



Users obtain variable resolution meshes through the specification of a single scalar function. Any number of refined regions of any shape and size are possible.

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- Jacobsen, D.W., M. Gunzburger, T. Ringler, J. Burkardt, J. Peterson, 2011: Parallel Algorithm for Spherical Delaunay Triangulations and Spherical Centroidal Voronoi Tessellations, Journal of Computational Geometry: Theory and Applications, submitted (pdf).

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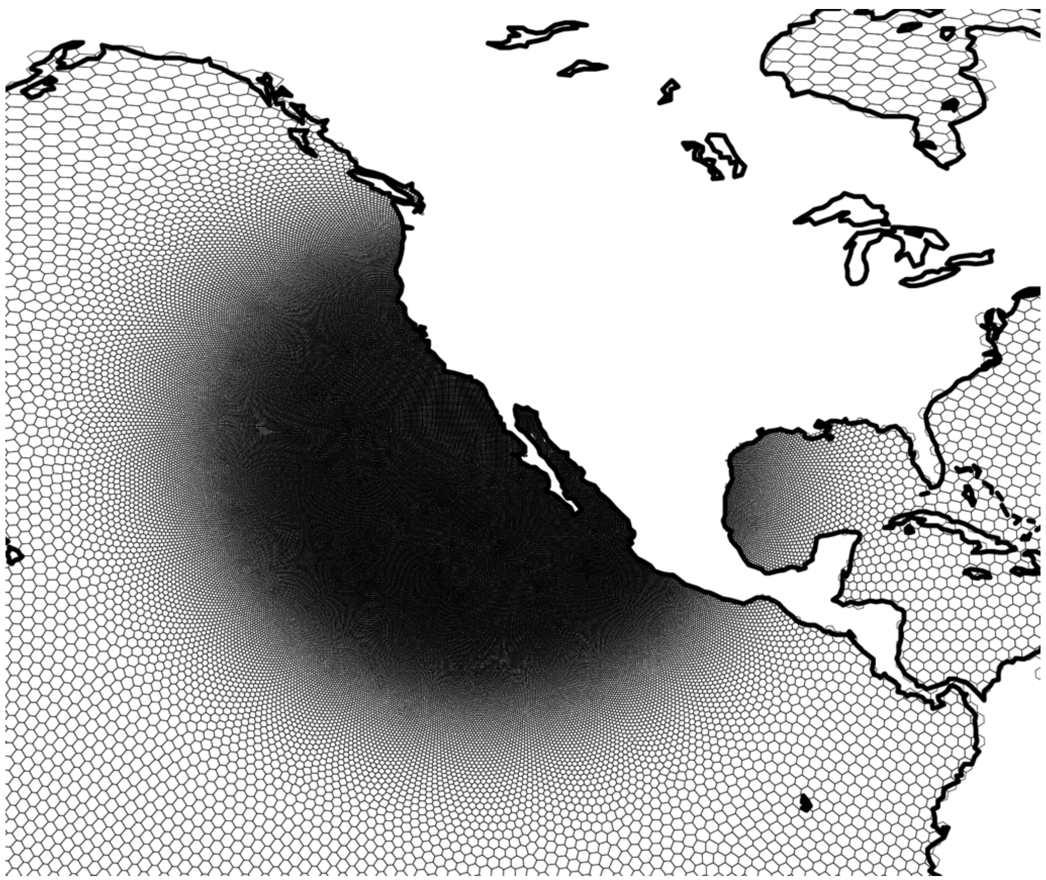
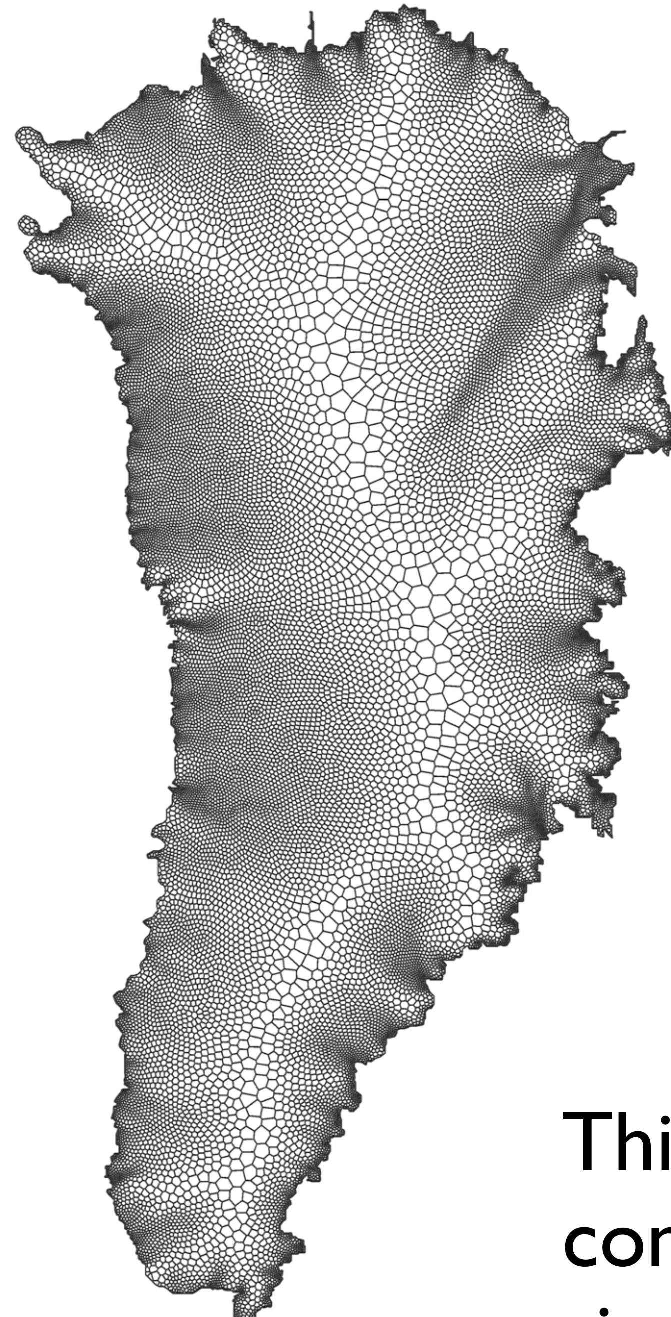
- Ju, L., T. Ringler and M. Gunzburber, 2009, Voronoi Tessellations and their Application to Climate and Global Modeling, Numerical Techniques for Global Atmospheric Models, Lecture Notes in Computational Science, draft. (pdf).

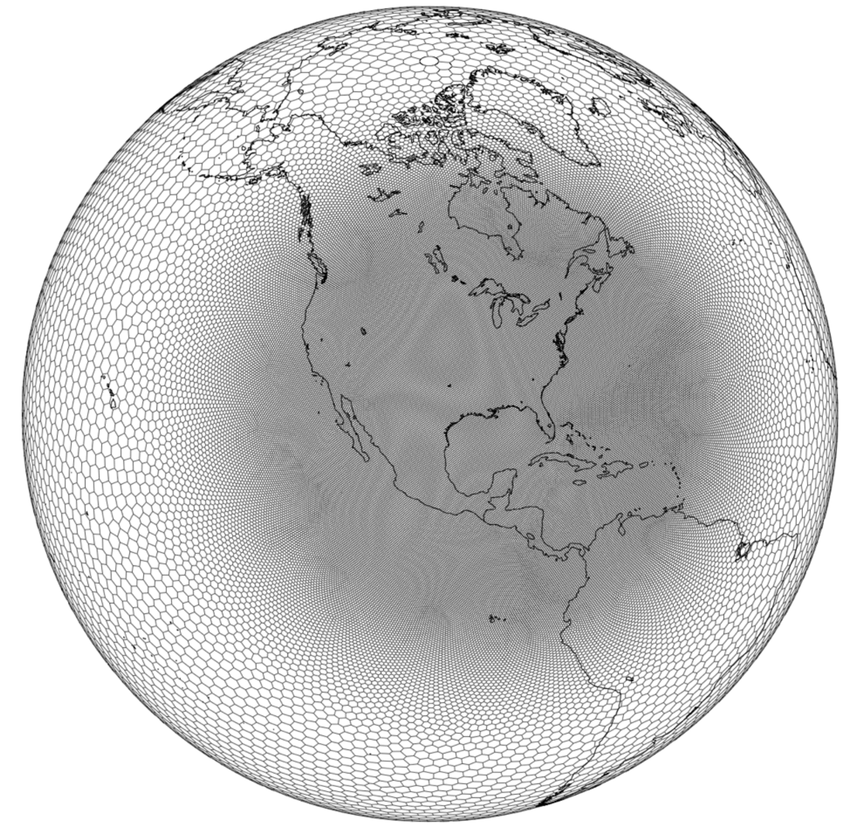
- Thuburn, J., T. Ringler, J. Klemp and W. Skamarock, 2009: Numerical representation of geostrophic modes on arbitrarily structured C-grids, Journal of Computational Physics, 2009: 228 (22), 8321-8335. doi:10.1016/j.jcp. 2009.08.006 (pdf)

- Ringler, T., L. Ju and M. Gunzburger, 2008, A multiresolution method for climate system modeling: application of spherical centroidal Voronoi tessellations, Ocean Dynamics, 58 (5-6), 475-498. doi:10.1007/ s10236-008-0157-2 (link)

This approach is being explored for each physical component of the NSF/DOE CESM.



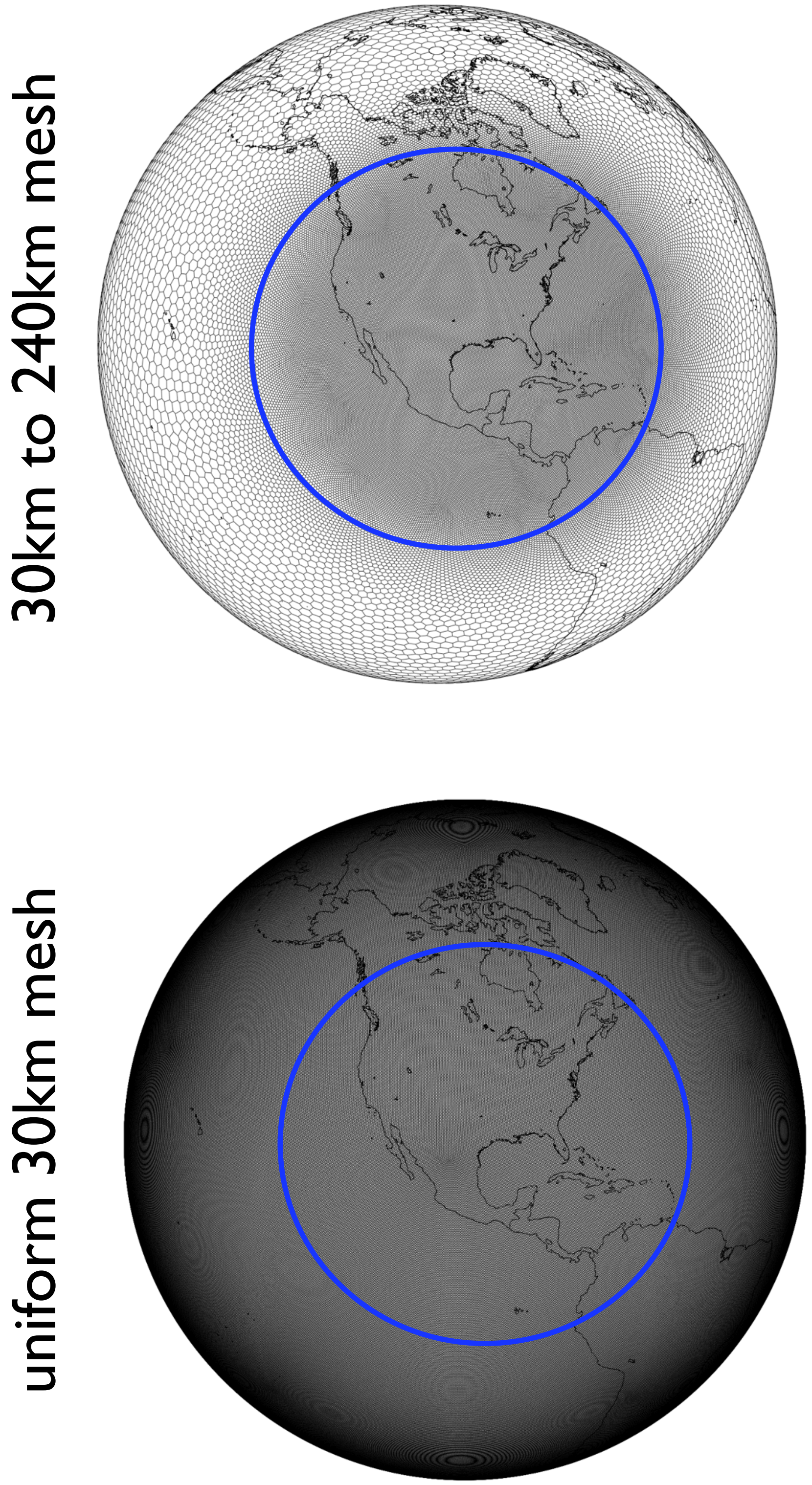


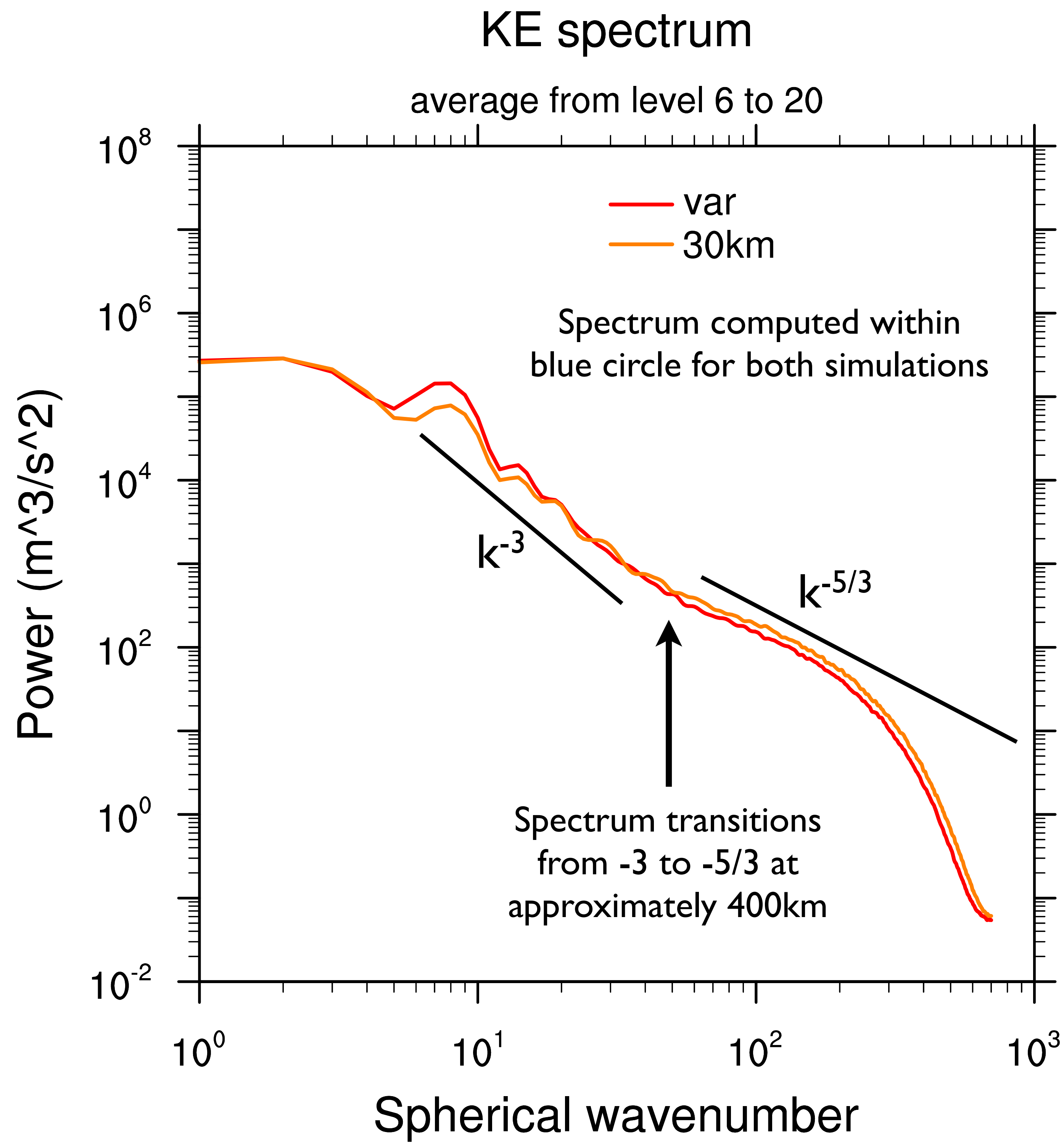


These models are being developed under the joint NCAR/LANL Model for Prediction Across Scales (MPAS) project.

This approach allows us to conduct regional climate simulations within a global modeling framework.

Success: A Robust Dynamical Core with Multi-Resolution Grids, Atmosphere

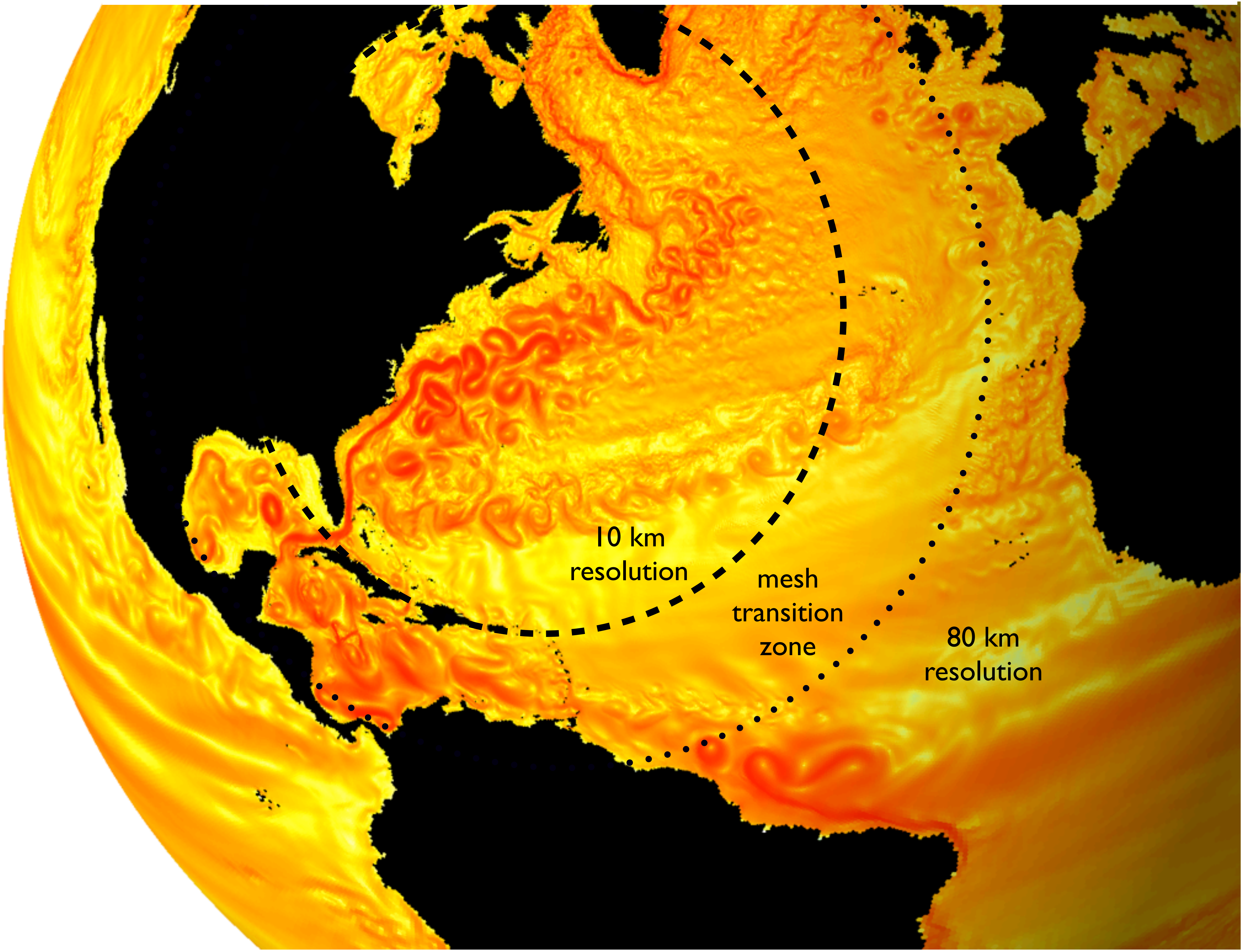




Full CAM4 physics using two meshes: a global 30km mesh and a variable 30km-240km mesh.
The energy spectra are, far all practical purposes, identical.

Success: A Robust Dynamical Core on Multi-Resolution Grids, Ocean

Surface kinetic energy from a global, real-bathymetry ocean simulation.



The global mesh has 10km resolution in the North Atlantic and 80km resolution elsewhere.

Significant eddy activity is associated with the North Atlantic current system, including evidence of the Northwest Corner.

Important conservation properties (mass, tracers, potential vorticity and energy) are maintained, even when using a variable resolution mesh.

Success: A Global Modeling Framework for Free, Analysis

$$N = \frac{8\pi}{\sqrt{3}} \left(\frac{R}{dx_f} \right)^2 \left[\underbrace{\sin^2\left(\frac{\alpha}{2}\right)}_{\text{high resolution}} + \underbrace{\frac{1}{\gamma^2}\left(1 - \sin^2\left(\frac{\alpha}{2}\right)\right)}_{\text{low resolution}} \right]$$

N : total number of degrees of freedom

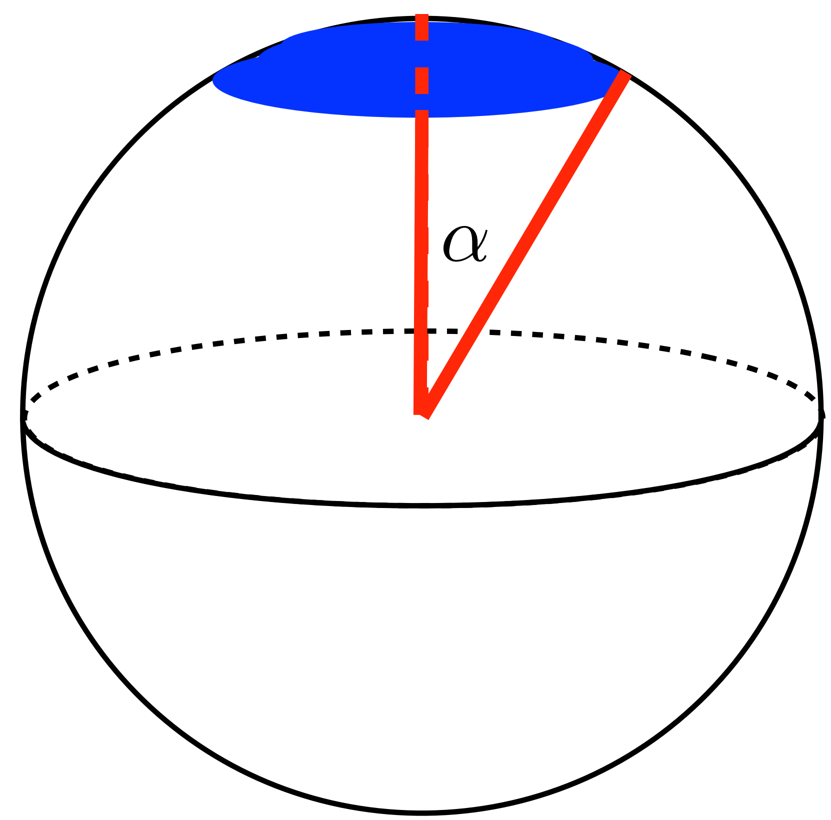
R : radius of sphere (km)

dx_f : grid spacing in high-res region (km)

α : angular width of high-res region (radians)

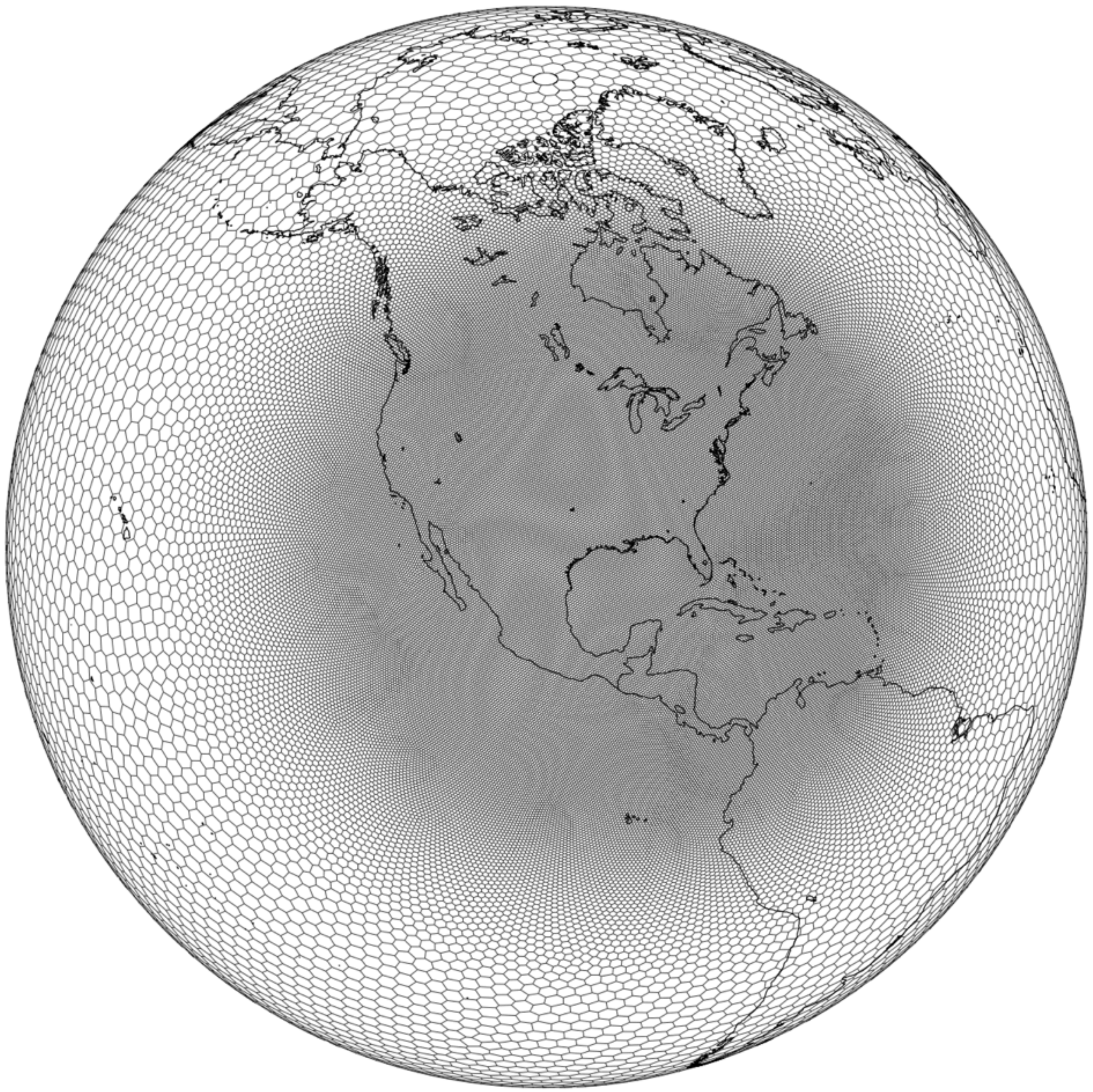
γ : low-res grid spacing / high-res grid spacing

region of
high resolution



For our North America mesh we have γ =8 and α =40 degrees.
More than 90% of our degrees of freedom residing in our high-resolution region.

Success: A Global Modeling Framework for Free, Implications



With 90% of the work in the high-resolution region, the "global framework" is obtained for only a 10% cost.

The cost-benefit makes the global, multi-resolution approach a compelling alternative to the limited-area approach.

This new modeling capabilities now presents the opportunity for the two communities to use the same global modeling framework.

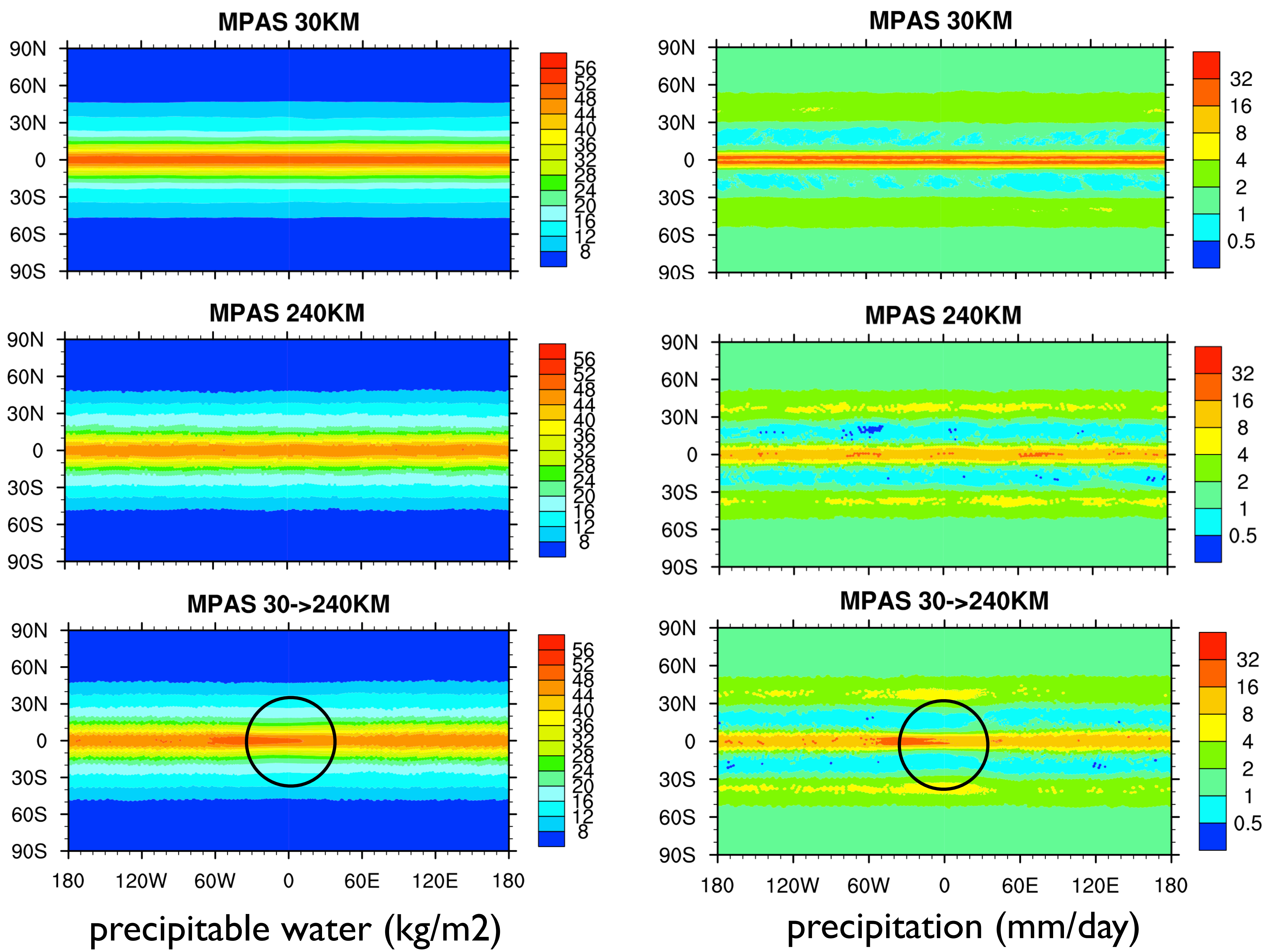
Challenges: Scale-Aware Physics, Atmosphere

Gross features of the climate, like precipitable water, change with resolution because of the action of the physical parameterizations.

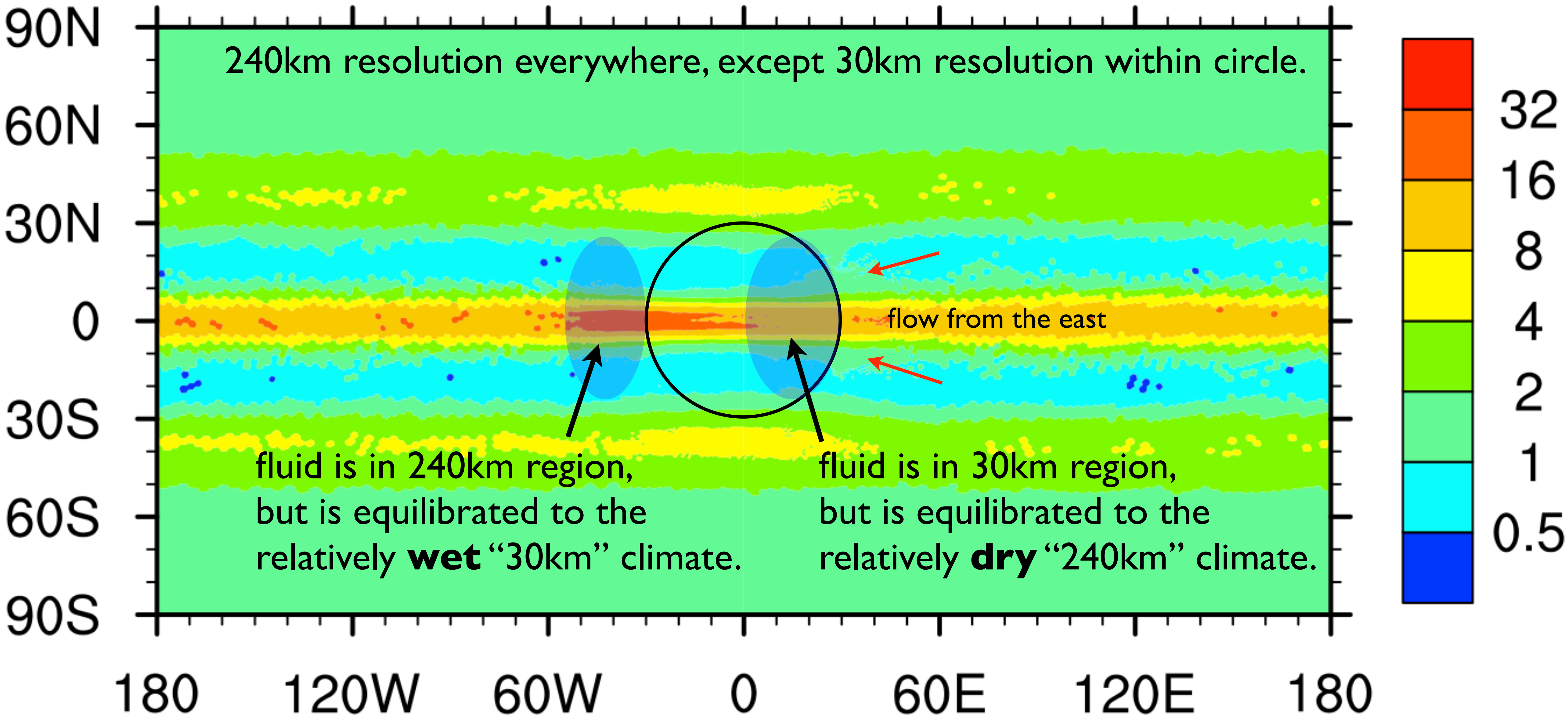
These are results from CAM4 physics run in aqua-planet mode forced with zonally-symmetric SST.

Precipitable water and precipitation change dramatically between the global 30km and global 240 km simulations.

Thus, for the variable resolution run, the flow into the 30km region is "balanced" for the 240km region.



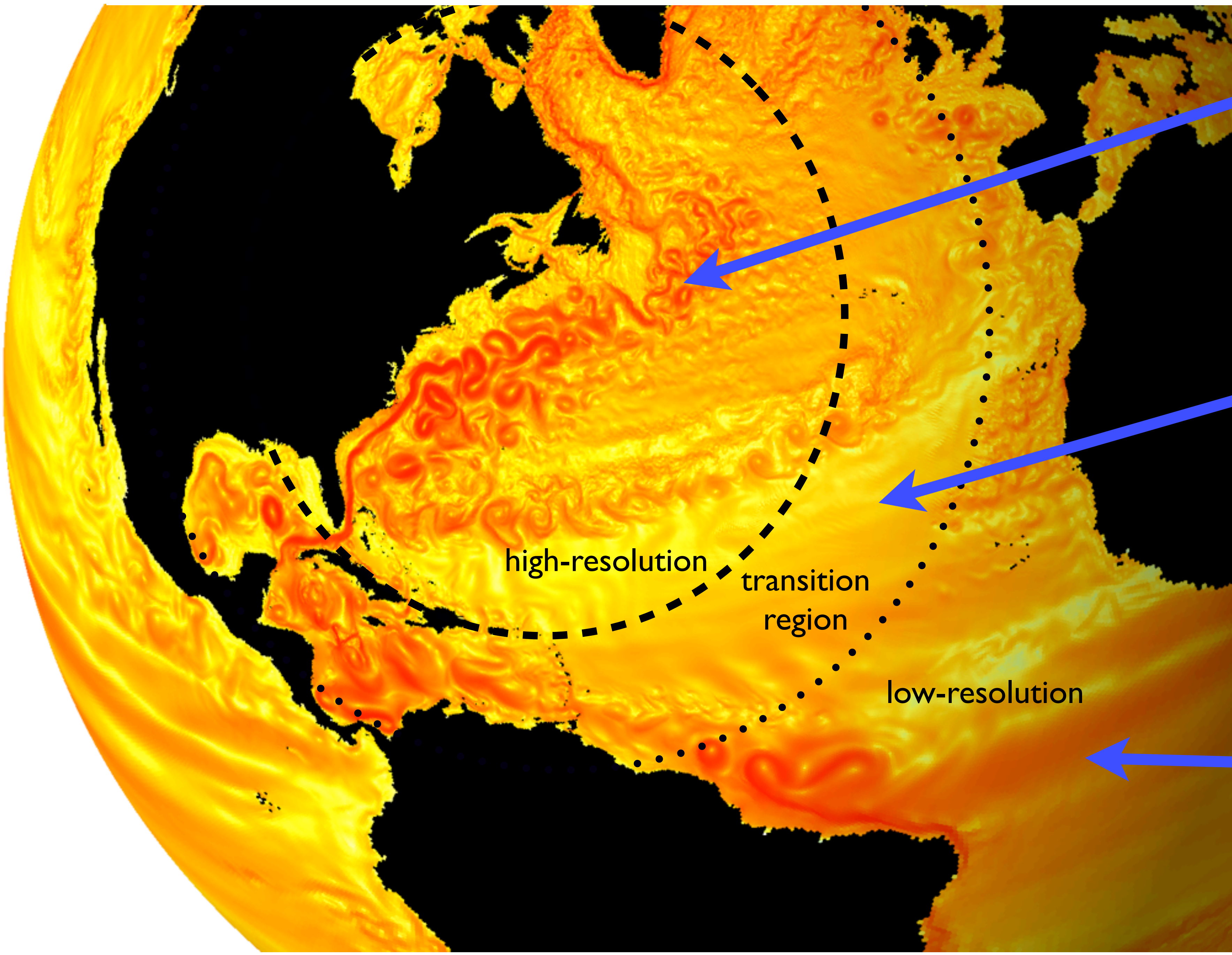
Challenges: Scale-Aware Physics, Atmosphere



This very simple setting provides a marvelous opportunity to create, implement and test scale-aware physical parameterizations.

Challenges: Scale-Aware Physics, Ocean

Mesoscale ocean eddies are an important mechanism for the poleward transport of heat. Thus, these eddies must be either resolved or parameterized.



Eddies permitted in this region, thus parameterization must be "turned off."

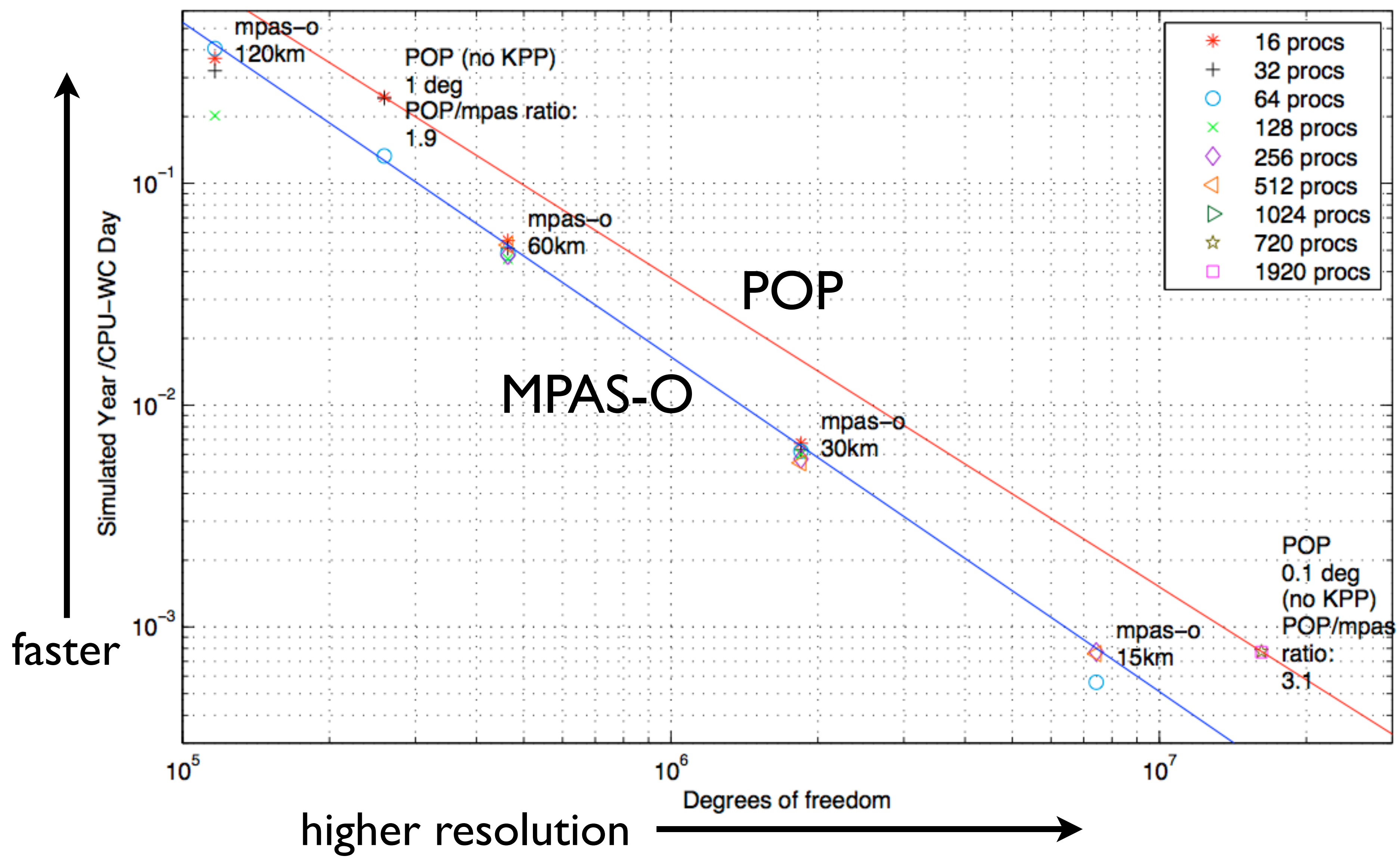
Not really sure what will happen here!

Eddies not resolved in this region, thus parameterization must be "turned on."

Challenges: Computational Efficiency

The flexibility in the mesh structure comes at the cost of having to leave the friendly world of structured data access for the brave new world of unstructured meshes.

Comparison between the Parallel Ocean Program (structured data)
and the MPAS Ocean model (unstructured data)



Per degree of freedom, MPAS-O is (presently) 2X to 3X slower than POP.

Conclusions

Prototype, multi-resolution, global atmosphere and ocean models are now being evaluated.

Early results are promising. When configured with multiple resolutions, these dynamical cores act like their globally-uniform counterparts at high and low resolution.

The grand challenge is now the creation of a suite of physical parameterizations that act appropriately across a wide range of spatial scales.

The effort needed to produce scale-aware physics will likely be significantly greater than was needed to produce scale-aware dynamical cores.